Individual time preferences and social discounting in environmental projects

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INDIVIDUAL TIME PREFERENCES AND SOCIAL DISCOUNTING IN ENVIRONMENTAL PROJECTS

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Abstract: The choice of an appropriate social rate of discount is critical in the decision-making process on public investments. In this paper we review the literature on social discounting, and address in particular a recently growing field of related research, that is, individual time preferences. We argue that an explicit consideration and analysis of the behaviour of individuals regarding the concept and the use of an appropriate social discount rate are essential for balanced decision making in the public sector, especially, though not exclusively, in the field of resource or environmental policy.

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1. Introduction

Policy making is based on decisions under uncertainty, including the economic assessment of the demand and consumption of scarce resources over time, which prompts the need to evaluate government interventions by explicitly considering the temporal dimension of public decisions. The construction of a road, for example, incurs investment costs (that start several years before the actual project implementation), while it creates flows of socio-economic costs and benefits that appear all along the project life cycle. The history of economic evaluations of public projects has shown that cost-benefit analysis may then be a proper tool.

If policy makers take an investment decision by employing the Net Present Value (NPV) rule, then they need to utilize a social discount rate meant to capture the opportunity costs of delaying current consumption in order to make the investment concerned possible. According to a standard formulation of Squire and van der Tak (1975), the social discount rate should reflect "*value judgements by the government [which] determine[s] the weight to be given to future consumption relative to present consumption*" (p. 26).

However, the ordinary use of discount rates in economic research remains controversial. The transfer of the concept of discounting in business investment (typically used for short-term productive sector projects with tangible marketed outputs) to the appraisal of often long-term, system-wide and normally highly uncertain effects has, over the years, prompted considerable discussion among economists. This discussion is driven by the fact that, while the private sector has tangible alternatives for the choice of the appropriate discount rate (such as the cost of acquiring capital), the social discount rate does not have a clear or unambiguous market-based foundation.

To cope with the above issue, a number of methods have been proposed in the early economic evaluation literature (Boardman et al. 2001):

- *Using the marginal rate of return on private investment*. Harberger (1969), for example, argued that public investment should outperform private investment in order to be financed by tax revenues; thus the rate of return on private investment is the opportunity cost faced by society when financing (through taxes) government capital expenditure.
- *Using the weighted social opportunity cost of capital*. Sandmo and Drèze (1971), among others, claimed that public investment crowds out private investment, thus producing the need to account for the opportunity cost of the use of resources used in the public project and which could be used by the private sector.
- *Using the shadow price of capital*. Eckstein (1958) and Bradford (1975) proposed to convert gains or losses resulting from an investment project into consumption equivalents. The proper conversion rate is then the shadow price of capital.

In recent years, a growing body of literature has considered the pure rate of time preference of individuals as a fundamental ingredient in the definition of the discount rate to be used in appraising public actions. This alternative originates from critical observations made by a number of well-known scholars in the field of cost-benefit analysis[1] for whom individuals entering a social contract commit themselves to increase their total savings to invest in projects that produce net benefits for future generations. This behaviour results in a collective rate of

[1] See, for instance, Baumol (1952), Eckstein (1958), Marglin (1963), and Sen (1961).

investment higher than the individual (i.e. private) preference rate. If this "isolation paradox" holds, then the discount rate for cost-benefit analysis should be below the private rate of return on savings, and reflects to some extent the individual time preference.

In this vein, the traditional Ramsey formula (Ramsey, 1928) captures both the pure time preference and other, more economically-oriented elements such as the expected growth rate of the economy and the risk associated with the relative uncertainty over future outcomes. According to Evans and Sezer (2004), the Ramsey formula for the calculation of the social time preference rate (*stpr*) can be approximated by the following simple expression:

$$stpr = r + \mu g \tag{1}$$

where r is the individuals' pure time preference; μ is the absolute value of the elasticity of marginal utility of consumption; and g is the projected long-run annual growth of *per capita* real consumption.

It is clear that the estimate of the *stpr* depends critically on:

a) an appropriate framework for defining r;

b) the assumed functional form of the utility function and its data approximation;

c) uncertainty about future economic conditions.

In recent studies (Evans and Sezer, 2004; Evans, 2004; Percoco, 2006), in the absence of strong empirical evidence, a 1-1.5% rate of pure time preference was suggested for some OECD countries (Australia, France, Germany, Japan, the UK and the USA) in order to calculate the *stpr*.

Recognizing the relevance and potential of individuals' pure time preference as a basis for evaluation analysis, we offer in this paper a review of the empirical literature on the estimation of r on the basis of experiments conducted on individuals, or based on inferences from their behaviour.

The paper is organized as follows. In Section 2, we review the relevant literature on the time preference of individuals; we give special attention to what, in the literature, is commonly called "anomalies". Sections 3 and 4 are a review of the early and contemporary debates on social discounting and the recent literature on environmental policy implications of different discount structures and/or rates respectively. In Section 5 we provide a summary and suggest pathways for future research.

2. Individual time preference

When studying the individuals' time preference, we have to assume implicitly how psychology shapes human judgement, in this case, over time. Samuelson (1952) and Koopmans (1960) may be considered as the fathers of the Discounted Utility (DU) model, even though the historical origins of this approach can be found in early works of Eugen von Böhm-Bawerk, John Rae and Irving Fisher (Frederick et al., 2002). In the DU model, an intertemporal utility function, $U^t(c_t,\ldots,c_T)$, is assumed to depend on consumption profiles $(c_t,\ldots,c_T)$ over a certain time horizon $t,\ldots,T$. The functional form describing a person's intertemporal utility function is:

$$U^t(c_t,\ldots,c_T) = \sum_{k=0}^{T-t} D(k)u(c_{t+k}) \tag{2}$$

where $D(k) = \left(\frac{1}{1+r} \right)^k$, r is the discount rate (i.e. the pure rate of time preference), and $u(c_{t+k})$ is the stream of utility from consumption at time $t+k$.

The DU model has some interesting, though not always realistic, features (Frederick et al., 2002), in particular:

a) a time-consistent preference, implied by the fact that in (2) the discount rate r is constant over the time horizon T;

b) a path-independent utility;

c) a time-independent consumption preference, i.e. the individual preference for consumption is not affected by past or future outcomes;

d) an independence of discounting from consumption, that is, the discount rate is not a function of consumption;

e) an integration of new alternatives with existing plans, i.e. additional consumption plans are evaluated by integrating them into current plans;

f) the instantaneous utility is constant for each given time interval;

g) a decreasing marginal utility.

However, as stated by Samuelson (1952) and demonstrated later on by Koopmans (1960), the DU model is not based on individual psychology, and hence it is not likely to be corroborated by empirical or experimental evidence. In what follows, we will highlight some prominent anomalies arising from empirical evidence on individuals' behaviour.

2.1 Hyperbolic discounting

Almost all discounting applications use the exponential discount factor and consider the discount rate as constant and independent of the time horizon. The main problem with this assumption is that recent experimental evidence on individuals' behaviour suggests that people's discount functions are hyperbolic, i.e. discount rates decrease over time. This fact implies an inconsistency in individuals' choices. An example taken from Kocherlakota (2001) clearly explains the behaviour underlying time inconsistency: "*Jan is about to go out to her neighbourhood bar. Before drinking anything there, Jan would like to sign a legally binding contract stating that she is allowed to drink only four beers that night. Why does she want to sign such a contract? She knows that after having four beers, she will want to have a fifth, and she wants to prevent herself from doing so"* (p. 13).

This example shows that Jan is exhibiting time-inconsistent preferences: her preferences for beer, at a given date and in a given state, may change over time without the arrival of new information.

Several models of time-varying discount rates have been developed and discussed by economists. Strotz (1956) was the first one who studied time-inconsistency in a dynamic framework. Phelps and Pollak (1968) introduced hyperbolic discount functions in an intergenerational context of consumption and saving. They captured taste for immediate gratification by means of a simple two-parameter model that modifies exponential discounting. Let u_t be the instantaneous utility of a person in period t. Then his intertemporal preferences at time t, U_t, can be represented by the following utility function, where both β and δ fall between 0 and 1:

$$U_t = \delta^t + \beta \sum_t \delta^t u_t \qquad (3)$$

The parameter δ determines how time-consistently patient a person is. If $\beta=1$, then these preferences imply exponential discounting. But for $\beta<1$, these preferences are time-inconsistent.

Decrease in timing aversion has been observed in experimental studies concerning *inter alia*: people choosing between non-monetary alternatives[2]; people choosing between monetary alternatives[3]; animals choosing between types of food or between other alternatives[4]. The main justification for the adoption of the hyperbolic discounting utility function is empirical evidence in the cognitive psychology literature which contradicts the predictions of utility functions with stationary fixed discount rates. However, as argued by Harvey (1994), many of these studies do not examine the decrease in people's discount rate as it becomes large, but rather the increase in their discount rate as time intervals become small.

In the empirical literature, there are two main types of experiments on the test of the hyperbolic discounting hypothesis. The first type was first discussed by Thaler (1981). Some people prefer 'one apple today' to 'two apples tomorrow' to 'one apple in one year'. Ainslie and Haslam (1992) report that *"[...] a majority of subjects say they would prefer to have a prize of a $100 certified check available immediately over a $200 certified check that could not be cashed before 2 years; the same people do not prefer a $100 certified check that could be cashed in 6 years to a $200 certified check that could be cashed in 8 years".* Experiments of this type have been replicated with choices involving a wide range of goods and a wide range of subject populations.

The second class of experiments is discussed in Thaler (1981) and Benzion et al. (1989). Subjects were asked to imagine that they had won a sum of money in a lottery, and that they

[2] See Christensen-Szlanski (1984); Cropper et al. (1994); Millar and Navarick (1984); Solnick et al. (1980). .

could either take the money now or wait for an increased amount later. They were presented with several variations of the amount \$$x$ at time t and the amount \$$y$ immediately. Then we may say that the subject's choice is consistent with the discount factor $D(r,t)$ defined by the equation:

$$y = D(r,t)x \tag{4}$$

The results show that the average discount rate is decreasing in t. However, it was also found that r is not constant, but rather an increasing function of t. The larger the sum of money at stake, the higher (closer to 1) the discount factor[5].

Rubinstein (2003), on the contrary, using experimental results, argues that the same sort of evidence which rejects the standard constant discount utility functions can reject hyperbolic discounting as well. Furthermore, a decision-making procedure based on similarity relations better explains the observations and is more intuitive. In summary, the findings of hyperbolic time preference rates show much variation and do not lead to clear and conclusive results.

2.2 Other anomalies

Hyperbolic discounting has certainly been the most debated time preference anomaly in recent years. However, other anomalies have been found as well in a number of experiments.

Often individuals appear to have a discount rate lower for losses than gains, exhibiting what is called the *sign effect*. Experimental evidence of such an anomaly is provided by Thaler (1981) and later on by Antonides and Wunderink (2001). On the other hand, Shelley (1994) found that individuals discount more a loss delay than a gain delay.

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[3] See Thaler (1981); Ainslie and Haendel (1983); Benzion et al. (1989); Horowitz (1996).
[4] See Ainslie (1975); Ainslie and Herrnstein (1981).

When small benefits are discounted more than large ones, we have the *magnitude effect* (Shelley, 1993). There is a consensus in the academic community about this anomaly in discounting, and several studies have been conducted in order to provide some more in-depth information about it. In fact, it has been documented that the effect is greater for smaller amounts and short delays (see, amongst others, Kirby, 1997; Green et al., 1997).

The *direction effect* postulates that discount rates depend on whether a change in time of delivery of a benefit is perceived as an acceleration or a delay from a reference point in time (Loewenstein, 1988). This anomaly was interpreted by Loewenstein (1988) as evidence of the plausibility of 'prospect theory'. For that paradigm, making an intertemporal choice means losing something at one time and gaining something at another. People's loss aversion behaviour implies that the substitute outcome needs to be considerably larger to compensate for the loss. For delay, the substitute outcome is the later amount, and hence the direction effect increases the discount rate; for expediting, the substitute comes out earlier, decreasing the discount rate[6].

The above description of the anomalies in individual discounting is certainly not comprehensive; it is mainly limited to those we think are more relevant from the viewpoint of social discounting and policy making[7].

Table 1 reports a summary of the features, and a simple analytical sketch of the anomalies presented in this section.

<<Table 1 around here>>

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[5] Keller and Strazzera (2002), by using data reported in Thaler (1981), examine the accuracy of the hyperbolic model vs. the exponential model and find a slightly higher effectiveness of the former.
[6] Recently, Caplin and Leahy (2004) proposed some arguments for the analysis of a benevolent government in the light of prospect theory.
[7] Besides the excellent paper by Frederick et al. (2002), a comprehensive survey on individual time preference features can be found in Read (2003).

At this point, the shortcomings of using a constant pure time preference rate in equation (1) should be clear. As the social discount rate formula is linear in *r*, a particular functional form for that term would influence the functional form of the social discount rate. For this reason, the recent debate on social discounting has focused on the aggregate implications of intertemporal preference anomalies, and pointed out some of the possible outcomes when individual characteristics are taken into account. In the next section, we offer a review of the recent developments in the theory of social discounting in the light of the features of individual preferences.

3. Social discounting

3.1 The theory of social discounting and the early debate

The Social Discount Rate (henceforth denoted SDR), as defined by the *stpr*, describes the trade-off between present and future consumption as a function of two components: a pure preference for present over future welfare (r), and another term (μg) which indicates that, if the expected growth in per capita consumption (g) is positive, then a unit of consumption in the future will yield less utility than in the present. The term μ is the absolute value of the elasticity of marginal utility with respect to consumption (a measure of the relative effect of a change in consumption on welfare).

The basis for the formal analysis of the SDR is offered by the Ramsey's (1928) classical growth model. In this approach, it is implicitly assumed that the economy reflects the preferences of individuals, and that "*these preferences ought to be reflected in the societal decision making process*" (Pearce et al., 2003). However, the consideration of intertemporal preferences is not without problems. Sen (1961) argues that, if in a democracy all people count in the decision making process, then there is no democratic solution to the intertemporal problem as future generations are not yet born. Eckstein (1958) argues that, if we consider the society to be driven by a sort of "consumers' sovereignty", then people's preferences, including their intertemporal ones, should be taken into account.

In his original formulation, Ramsey (1928) assumes an ethical position stating that discounting "*is ethically indefensible and arises merely from the weakness of the imagination*" (Ramsey, 1928). By relying on Arrow and Kurz (1970) and Koopmans (1960), Markandya and Pearce (1988) provide a simple derivation of the *stpr*, as defined in equation (1). Let us consider social welfare (W) at time t as a function of consumption at the same point in time (C_t), and formalized as:

$$W(C_t) = C_t^{1-\mu} e^{-rt} (1-\mu)^{-1} \tag{5}$$

The present value of social welfare if the consumer maximizes his consumption stream is such that:

$$W'(C_t) = \frac{W'(C_{t+1})}{1+stpr}, \tag{6}$$

which is equivalent to:

$$stpr = \frac{W'(C_{t+1}) - W(C_t)}{W'(C_t)} = \frac{\frac{dW'(C_t)}{dt}}{W'(C_t)}, \tag{7}$$

Substituting the derivatives of (5) into (7) yields:

$$stpr = \mu \frac{dC}{dt} C^{-1} + r, \tag{8}$$

Clearly, since $\frac{dC}{dt}C^{-1}$ is the growth rate of consumption (*g*), we directly obtain (1).

As stated in Section 1, the empirical definition of the *stpr* depends on expectations of the growth rate of the economy, as well as on the pure time preference of individuals, as expressed by *r*, while both elements are characterized by a high degree of uncertainty. For this reason, there is no consensus, neither in the economic literature nor among policy makers, on the value of the SDR to be adopted[8]. As a consequence, there is high volatility in the computation of the SDR in both scientific studies and in practical guidelines, as reported in Tables 2 and 3.

<<Tables 2 and 3 around here>>

In particular, Table 2 reports general discount rates for several industrialized countries. It is shown that they vary between 3.5% for France and 6% for the UK. Greater variation is shown for SDRs for carbon sequestration projects as reported in Table 3. The information given in this table should be considered only as an example of SDR variation for sector-specific projects; in fact, rates of discount may vary in the interval [0%, 10%].

3.2 The contemporary debate

From formula (1) or (8), it is clear that the estimation of the pure rate of time preference of individuals, *r*, is crucial for the definition of the *stpr*. Sen (1967) argues that people enter into a social contract, in which they commit themselves to increase their total savings above the level they would choose privately, exhibiting what is widely known as the "isolation paradox". As a consequence, the SDR, if assumed to be just *r*, is lower than the market rate. Warr and Wright

[8] Actually, Rabl (1996) proposes a completely different approach, where the classical discount rate is applied for the short term (less than 30 years) and the growth rate of the economy for the long term.

(1981) claim that the "isolation paradox" does not necessarily imply a non-market SDR[9]. However, Newberry (1990), arguing against Warr and Wright (1981), shows that their analysis holds only under conditions of sub-optimal equilibria. In our opinion, the analysis in Sen (1967) points out the central role played by individuals' preference in shaping public decision making, or, in other words, the fact that collective actions result from the aggregation of individual preferences.

As stated in the previous section, consumers' time preferences are characterized by decreasing discount rates. One of the first attempt at studying hyperbolic consumers in the context of public policy was made by Cropper and Laibson (1999). They show that, if agents are quasi-hyperbolic, then they consume more and save less, suggesting a role for the government to subsidize interest rates through public expenditure. In their analysis, they do not provide an explicit rationale to use hyperbolic discounting as a social practice.

By explicitly addressing the aggregation issue, Gollier (2002) and Gollier and Zeckhauser (2003) demonstrate that the aggregation of preferences of exponential individuals leads to hyperbolic discounting of collective action outcomes. This result is very interesting, as it provides a convincing rationale for the use of time-declining discount rates. To this debate, additional arguments have been provided by Azfar (1999) and Weitzman (1998), who argue that the presence of uncertainty leads agents to have decreasing discount rates[10]. Weitzman (1998) also states that there are at least three reasons to use a time-declining discount rate in evaluating far-distant future effects of a given project or policy:

[9] Horowitz (1996) shows that the choice of a non-market discount rate leads to time-inconsistent policy which is a feature of government action in several fields. For a survey on time inconsistent fiscal and monetary policy making, we refer to Catenaro (2000).

[10] It should be noted that some arguments on uncertainty over future outcomes are also present in the analysis proposed by Gollier (2002) and Gollier and Zeckhauser (2003).

a) there is strong empirical evidence that individuals use lower discount rates for events that occur farther into the future;

b) a sufficiently large positive discount rate gives negligible weight to costs and benefits that occur far into the future; using a time-declining rate avoids having to choose between ignoring very long-term environmental consequences (with a time-invariant, non-zero rate) and not discounting at all;

c) current market rates of interest or marginal rates of time preference reflect the preferences of individuals currently alive, not those not yet born. In other words, future impacts should have exactly the same weight as current impacts.

The second point, that is, a discount rate that declines over time and ascribes higher values to future net benefits, is a feature of particular interest for resource and environmental policy. In fact, many environmental projects and programmes are characterized by high short-run costs and net benefits that show up in the far distant future, and the use of a discount rate declining over time may lead analysts to accept a larger number of projects that produce environmentally-benign outcomes. In order to highlight this fact, in the next section we review some of the most relevant literature on the effect of time-declining discounting on environmental policy in a broad sense.

4. Relevance of social discounting for resource and environmental policy

Since the publication of the seminal paper by Nordhaus (1994), it has become clear that the choice of the discount rate/function deeply affects the choice and the making of environmental policy[11]. Newell and Pizer (2001) find that costs and benefits in the distant future such as those associated with global warming, long-lived infrastructure, hazardous and radioactive waste, and biodiversity often have little value today when measured with conventional discount rates. They demonstrate that when the future path of this conventional rate is uncertain and persistent (i.e. highly correlated over time), the distant future should be discounted at lower rates than suggested by the current rate. They then use two centuries of data on U.S. interest rates to quantify this effect. Using both random walk and mean-reverting models, they compute the certainty-equivalent rate, that is, the single discount rate that summarizes the effect of uncertainty and measures the appropriate forward rate of discount in the future. They estimate discount factors over the next 400 years based on a 4% rate of return in 2000. Discount factors are expressed in terms of the value today of $100 provided at various points in the future, that is, the discount factors multiplied by 100. After only 80 years, conventional discounting at a constant 4% undervalues the future by a factor of 2, relative to the random walk model. Going further into the future, conventional discounting is off by a factor of over 40,000 after 400 years. The mean-reverting model produces less huge, but yet still significant, results, raising the discount factor by a multiple of about 130 after 400 years. It is noteworthy that the shortcomings of the constant discount rate (i.e. the exponential model) can be somehow overcome by using a time-declining discount rate (Newell and Pizer, 2001).

Similarly, Pearce et al. (2003) reported that the present value of the marginal damage of carbon emissions in the UK is extremely sensitive to different discount profiles. In particular, they find that by using a flat 6% discount rate, as suggested in the Green Book by the HM Treasury (1997) and reported in Table 2 of the present paper, the social cost of pollutant emissions is

[11] For a different perspective, criticizing the characteristics of the model used by Nordhaus (1994), see Neumayer (1999).

underestimated by almost 200% with respect to the case of discounting *à la* Newell and Pizer (2001).

Previous arguments and evidence thus call for a special care when discounting streams of costs and benefits of environmental policies and projects. In this vein, Weitzman (1994) was the first to propose an "environmental discount rate". His line of reasoning runs as follows. A marginal investment creates economic growth as well as a need to increase expenditure to ensure that environmental quality remains unchanged. This cost reduces the return on investment, so that an adjustment of the discount rate is needed. Environmental expenditure is increasing over time, and hence the rate of discount should be considered as time-varying. Later on, this intuition led the author to formulate the analysis summarized in Weitzman (1998).

More recently, the link between discounting and sustainability has become more clear as discounting the future using declining discount rates implies a higher level of altruism with respect to the exponential function (Saez-Marti and Weibull, 2005). This is an important feature, as one of the requirements for sustainable development is the intergenerational equity, that is, an adequate level of intertemporal altruism. These results are substantially in line with the framework proposed by Chichilnisky (1996) to analyze sustainable development, where decision makers maximize the discounted value of net benefits and the well-being of far-distant future generations.

It is interesting to notice that, while the use of hyperbolic discounting is desirable from an environmental point of view, it has no negative effects on economic growth. In fact, Barro (1999) modified the neoclassical growth model to allow for a non-constant rate of time preference. He finds that if the household cannot commit to future choices of consumption, and if utility is logarithmic, then the equilibrium resembles the standard results[12]. By explicitly considering environmental quality, Li and Lofgren (2000) find that a decrease of the discount rate in the long run increases the social welfare in the steady state of a classical development model.

It is noteworthy that the use of hyperbolic discounting is of enormous importance for what is considered to be the currently most relevant environmental issue, i.e. global warming. Karp (2004) addresses this issue and finds that, in the case of a benevolent government able to commit to future actions, optimal emissions (and consequent abatement) match the outcome under hyperbolic discounting.

All those arguments and results lead us to conclude that the SDR certainly matters in public choices as is witnessed by the literature on resource and environmental policy. As a consequence, the SDR should not be taken as a merely exogenous variable in the policy making process, it should be rather considered as a fundamental ingredient with which governments can shape the future of economies and societies.

5. Conclusions

In this paper we have reviewed the literature on social discounting, and pointed out how individual preferences shape the social discount rate. However, people's intertemporal preferences present some anomalies that undermine the validity of the classical model that relies on an exponentially discounted utility. One of these anomalies is that individuals present time-decreasing discount rates, exhibiting what is widely called "hyperbolic discounting". It has been

[12] By relying on Barro-type growth models, Michel et al. (2004) conduct an extensive study on the effect of altruism on the effectiveness of fiscal policy. They find that when individuals have different degrees of altruism, public debt

pointed out that the use of hyperbolic discounting is rational in evaluating public policies if uncertainty affects future outcome and when the SDR results from the aggregation of exponential consumers. The use of such a function has some positive environmental policy implications when considering interventions showing net benefits occurring in the far-distant future, as in the case of policies against global warming.

Finally, a word on future research, which we feel should be conducted mainly in two fields. Blundell and Stoker (2005) point out the importance of heterogeneity treatment in the estimation of economic aggregates. Gollier and Zeckhauser (2005) provide some necessary and sufficient conditions for the aggregation of individual time preferences into a social aggregate under very strict conditions. On this point, by using large data sets, such as the households surveys provided by most industrialized countries' governments or central banks, it would be interesting to investigate the cross-section distribution of individual discount rates, as well as to verify some of the basic theoretic postulates that can be drawn from the literature on the aggregation of preferences. Secondly, Laibson et al. (2004) propose the use of a general model to estimate individual discount functions by making use of simulated moments estimation procedures on data on credit card borrowing in the U.S. In the European context, it would be very useful to estimate such functions, as well as to investigate in this framework the impact of aggregation of time preferences.

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Table 1: Discount models and their characteristics

Model/Anomaly	*Choice*	*Characteristics*	*References*
Exponential	$u(x_1) = u(x_2)$	The discount factor is: $\left(\frac{1}{1+r}\right)^t$	Samuelson (1952)
Hyperbolic	$u(x_1) = u(x_2) = u(x_3)$	The discount factor is $\left(\frac{1}{1+\alpha t}\right)^{\beta/\alpha}$ that approximates a discount factor with r(t)	Loewenstein and Prelec (1992)
Sign effect	$u(x_1^+) = u(x_2^+)$ $u(x_1^-) = u(x_2^-)$	$\frac{x_1^+}{x_2^+} > \frac{x_1^-}{x_2^-} \Rightarrow r^+ > r^-$	Antonides and Wunderink (2001); Thaler (1981)
Magnitude effect	$u(x_1^S) = u(x_2^S)$ $u(x_1^L) = u(x_2^L)$	$\frac{x_1^L}{x_2^L} > \frac{x_1^S}{x_2^S} \Rightarrow r^L > r^S$	Shelley (1993)
Direction effect	$u(x_1) = u(x_2^D)$ $u(x_1^E) = u(x_2)$	$\frac{x_1}{x_2^D} > \frac{x_1^E}{x_2} \Rightarrow r^D > r^E$	Loewenstein (1988)

NOTES: This table relies on results and notation in Read (2003). In the second column "Choice" are the choices an individual faces when testing different models/anomalies. In the third column "Characteristics" are the main results from the experiment/model.

LEGENDS: The sign "=" means that the individual has to make a choice or to reveal a preference. For instance, $u(x_1) = u(x_2)$ means that an individual is asked to reveal his discount rate for which he is indifferent in having x at time $t=1$ or at time $t=2$. Subscripts denote time t= 1,2,3; r is the discount rate; α,β are parameters of the generalized hyperbolic model. Superscripts' meanings are as follows: +: gain; -: loss; S: small; L: large; D: delayed; E: expedited.

Table 2: A sample of Social Discount Rates across countries

Country	*Social Discount Rate*	*Source*
Australia	4.7%	Evans and Sezer (2004a)
Canada	5.2%	Kula (1984)
EU	5%	European Commission (2002)
France	3.8%	Evans (2004)
France	3.5%	Evans and Sezer (2004)
Germany	4.1%	Evans and Sezer (2004)
Italy	3.7-3.8%	Percoco (2006)
Japan	5.0%	Evans and Sezer (2004)
UK	4.2%	Evans and Sezer (2004)
UK	3.71-4.84%*	Evans and Sezer (2002)
UK	6%	HM Treasury (1997)
USA	4.6%	Evans and Sezer (2004)
USA	5.3%	Kula (1984)

(*) The range is due to different assumptions on altruistic behaviour

Table 3: Social Discount Rates for Carbon Sequestration Projects

Country	*Social Discount Rate*	*Source*
Brazil	0-5%	Fernside (1995)
Global	6%	Nordhaus (1991)
Malaysia	0-3%	Ismail (1995)
Malaysia	6-10%	Boscolo et al. (1997)
Norway	2-7%	Hoen and Solberg (1994)
USA	4-8%	Moulton and Richards (1990)
USA	10%	Adams et al. (1993)
USA	2.5-10%	Stavins (1999)
USA	4%	Parks and Hardie (1995)
USA	2-10%	Englin and Callaway (1995)

NOTE: This tables relies on data reported in Boscolo *et al.* (1998).